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Volume compilation procedures in Forest Management Inventories

M.D. Gillis and J.A. Edwards

Information Report PI-X-79
Petawawa National Forestry Institute

89-02346/

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VOLUME COMPILATION PROCEDURES IN FOREST MANAGEMENT INVENTORIES

M.D. Gillis and J.A. Edwards

Information Report PI-X-79
Petawawa National Forestry Institute
Forestry Canada
1988

©Minister of Supply and Services Canada 1988
Catalogue No. Fo45-11/79-1988E
ISBN 0-662-16624-8
ISSN 0706-1854
Printed in Canada

Copies of this publication may be obtained free of charge from the following address:

Publications Distribution Centre
Petawawa National Forestry Institute
Chalk River, Ontario
K0J 1J0

Telephone: 613-589-2880

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Abstract

Forest inventory compilation procedures and the application of inventory estimates arising from the compilations have not been described in the literature. To fill this gap a survey of provincial and territorial compilation procedures was undertaken, and a common forest inventory process, or model, emerged.

This report describes components of the model and lists characteristics of provincial inventory procedures as they relate to the model. Weaknesses associated with the inventory process relate more to the understanding and application of the model than to the individual components. The main problems are associated with the sequencing of components, photo interpretation, the establishment of sample units, and the application of single tree equations. Although the individual components of the model are likely to change in the future the basic compilation process is expected to remain valid. An example of a forest inventory procedure is contained in an appendix.

Résumé

Les méthodes d'inventaire forestier et l'application des résultats obtenus à l'aide de ces inventaires n'ont pas été décrites dans les publications. Pour combler cette lacune, une étude des méthodes utilisées dans les provinces et les territoires a été entreprise, et il s'en est dégagé un processus, ou un modèle, commun d'inventaire forestier.

Le rapport décrit les éléments du modèle et énumère les caractéristiques des méthodes provinciales d'inventaire qui sont en rapport avec le modèle. Les lacunes du processus d'inventaire ont trait à la compréhension et à l'application du modèle plutôt qu'aux éléments individuels. Les principaux problèmes concernent la mise en séquence des éléments, l'interprétation des photographies, l'établissement d'unités d'échantillons et l'application d'équations pour les arbres pris individuellement. Il est probable que les éléments individuels du modèle changeront, mais on croit que le processus fondamental d'inventaire demeurera valide. Un exemple d'une méthode d'inventaire forestier est donné en annexe.

Introduction

A forest inventory is a survey of an area to determine the volume, location, condition, composition, and structure of the forest resource for planning, management, and evaluation purposes. Of the different types of forest inventory employed in Canada, the forest management inventory is the most common and important. It evolved in the 1950s in response to a requirement for better forest management information. Figure 1 illustrates the relationships among the planning, mapping, sampling, compilation, and update phases of a typical management inventory.

The planning phase outlines the objectives of the inventory, identifies data requirements, creates the framework for area and volume classification, and establishes the sampling design required to achieve objectives. Timing, scheduling, budgeting, and personal logistics are also described in the planning phase.

The mapping, sampling, and compilation phases include all the steps or technical components required to produce the desired results. The update phase maintains the inventory to serve an ongoing forest management planning process.

Forest inventory in Canada is primarily a provincial responsibility. The federal government is involved in the areas of research and development, compilation and summation of provincial data for national statistics, and in the inventory of federally administered lands. The provincial inventories have elements in common and the methodologies are generally well documented (see Nietmann 1987). What has not been well documented is how the technical components are linked to derive the common forest inventory statistics, i.e. stem frequency, basal area, and the several expressions of volume (Canadian Forest Inventory Committee 1985).

This report presents an overview of the forest inventory process and describes individual components as they relate to volume compilation. Strengths and weaknesses associated with the compilation procedure are discussed. The report concludes with a brief description of forest inventory as it relates to the compilation procedure. The characteristics of provincial forest inventory procedures connected with the overview are contained in Appendix 1. This overview is intended to assist an understanding of Canadian forest inventory practice, especially that involved in the calculation and compilation of the statistics required for forest management.

Forest Inventory

Forest inventory in Canada is part of an overall forest management information cycle (Figure 2). The volume compilation aspect of the process can be described best by grouping components into three categories: input, volume estimation, and reporting. The components are linked to generate common forest inventory statistics. Figure 1 shows these components of the forest inventory process, and the italicized numbers that follow refer to numbered labels in the figure.

Input

The input components include the forest type map (3), the individual tree equations (5), and the volume sample units (*8* and *9*). Forest type map information is created by combining planimetric data, gathered from base maps, with thematic data derived from the interpretation of aerial photographs (2) according to the classification system (*1*). Accompanying the map is a stand attribute list, containing a descriptive label for each delineated forest stand or polygon on the map.

The forest stand delineation used to construct the map is the framework for sampling. The sampling intensity is determined by the variability within the forest and the desired accuracy, as stated in the objectives. The map information is used to stratify the forest (*6*) into subpopulations (strata) of interest to the user. A stratum is typically defined by combinations of classification criteria that are significant to the management of the resource, e.g. a combination of forest type, major species, height, and crown closure within a certain region. A stratum is an aggregation of stands having the same defined criteria in their descriptive label. Stratification is done to reduce sample variance and improve sampling efficiency. Sample units are located within a stratum with sufficient intensity to meet inventory objectives. Map information is also used to determine the location of sample units (*7*) within strata.

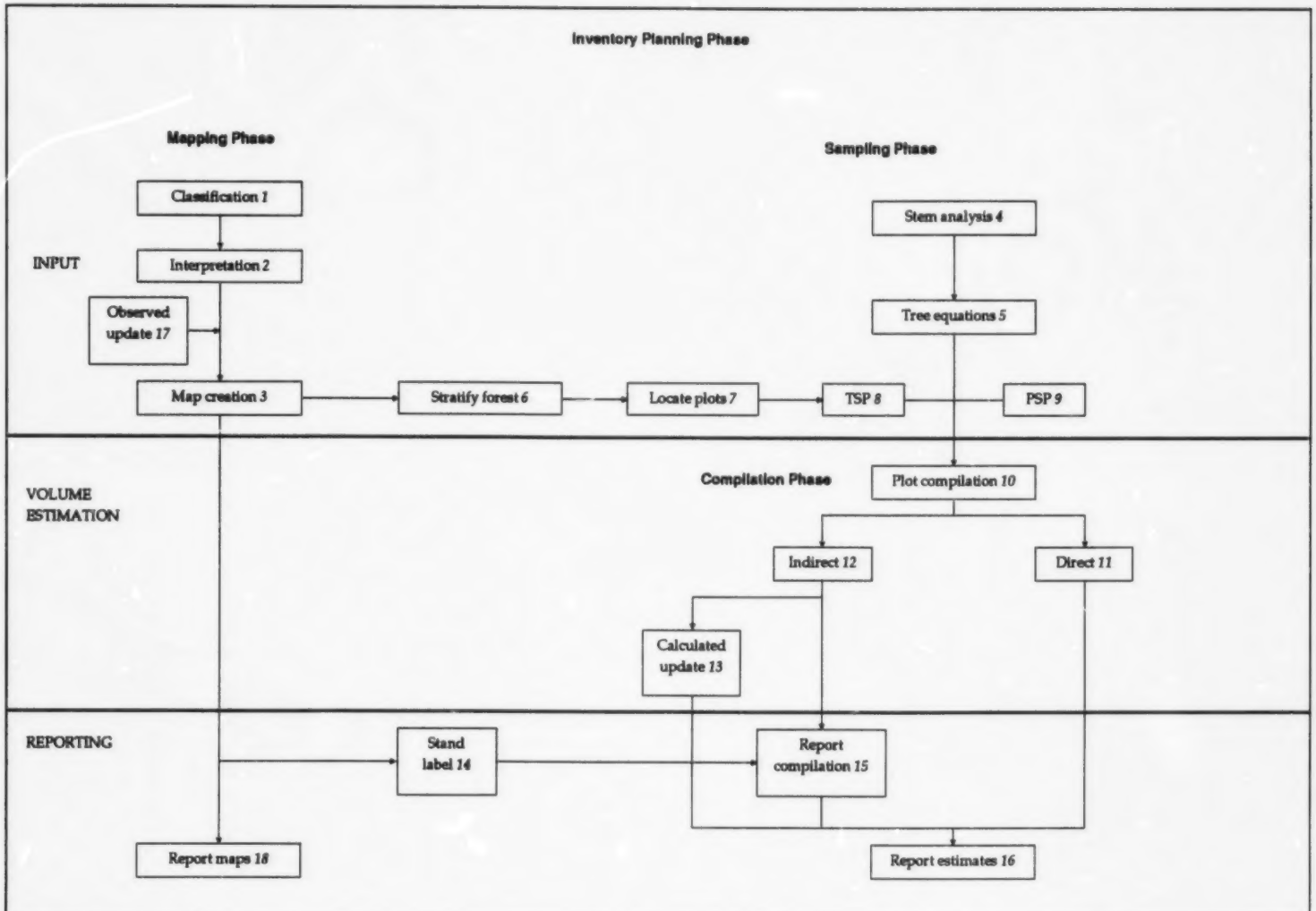

Figure 1. The forest inventory process.

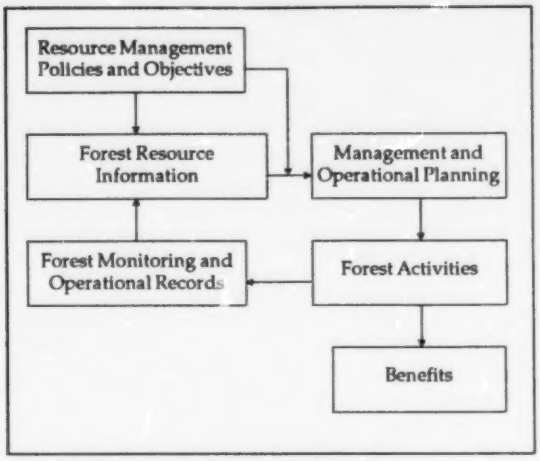

Figure 2. The forest management information cycle.

Sample units may be either temporary or permanent. Temporary sample plots, TSPs (*8*), are an essential part of the inventory. They are used to estimate forest inventory statistics by species, diameter distribution, and merchantability, to estimate stand height, and to obtain qualitative information such as stand condition, including age. Temporary Sample Plots are also used to calibrate air photo interpretation. Permanent sample plot, PSP (*9*), data differ from TSP data primarily in their added dimension of time and they are established to meet different objectives. Permanent Sample Plots are often used along with TSPs in the estimation of forest inventory statistics. The periodic remeasurement of PSPs provides data for quantification of growth and yield and stand development over long periods of time. Data from TSPs can also be used to develop or strengthen yield equations. The map cover type description is attached to the plot data for grouping purposes in the compilation phase.

Single tree equations are constructed from stem analysis data. Representative sample trees are analyzed (*4*) to determine how the dimensions of the tree (i.e. height, diameter, and form) are interrelated. This information is required in the construction of single tree volume and taper equations (*5*), and can be used to create cull and decay factors. The dimensions may also be studied relative to their development over time to contribute to the development of growth and yield equations.

Volume Estimation

The objective of a forest management inventory is to provide an estimate of the volume, location, condition, composition, and structure of forest resources. Volume estimates may or may not be accompanied by a statement of statistical precision. An inventory may be static, providing an estimate of resources at a specific point in time, or dynamic, capable of providing an estimate of future as well as present resources.

Single tree equations (*5*) are applied to the sample plot data in plot compilation (*10*) to produce single tree estimates of the forest inventory statistic of interest. An area expansion factor is applied to the single tree estimates to derive plot estimates. Sample plot estimates are then used to derive the inventory estimates. An example of the volume estimation procedure is illustrated in Appendix 2. Inventory estimates may be expressed in a number of forms. Discount or reduction factors may be applied to the estimates to derive additional information. For example, gross total volume minus unmerchantable branches, top, and stump yields gross merchantable volume. A further reduction for decay, breakage, or cull yields a net merchantable volume estimate.

Some inventories use two distinct methods to produce the final estimates (see Table 1). These are the direct method used to produce the key statistics, and the indirect method (*12*) using representative stand "look up" tables.

Direct Method

The direct method of estimation (*11*) involves the direct compilation of sample unit estimates to calculate the inventory estimate. There are two applications of the direct method.

The first application of the direct method occurs when sample units are geographically located within a stratum. In this case sample unit estimates are combined to calculate a mean value per hectare for the statistic of interest (e.g. volume), accompanied by a precision estimate. Stratum area is determined from the map and stand attribute list, and applied to the per hectare value and to the estimate of precision to compute total volume and its sampling error. A variation of this application is to apply stratification when the inventory results are being compiled (post-

Table 1. Compilation methods for forest inventory statistics according to sample unit location

Method	Sample unit location	
	Within stratum	Outside stratum
Direct	- sample units are allocated to strata in the original design or during compilation	- sample units from other locations are applied to stratified stands.
	- sampling error can be estimated.	- sampling error cannot be estimated.
Indirect	- sample units are allocated to strata and used to calculate representative statistics.	- representative statistics from other locations are applied to mapped stands.
	- sampling error can be calculated for the stratum.	
	- sampling error cannot be calculated when representative statistics are applied to mapped stands.	- sampling error cannot be calculated when applied on a stand by stand basis.

stratification). Stands may be post-stratified according to any combination of classification criteria. Sample units are stratified in the same way and unit estimates are averaged to compute per hectare statistics. The per hectare statistics are applied to stratum area to compile the inventory estimate. This estimate will also have an associated estimate of precision.

The first application is typically used to provide the key statistics to satisfy the primary objective of inventory. The sampling error in the case of post-stratification will not be known until the compilation is carried out. Neither estimate can be reported at the stand level with a statement of statistical confidence (i.e. probability of the true mean to be within a given range).

The second application of the direct method is relevant when no sample units exist within the stratified area. In this case the inventory estimate may be compiled from sample units representing a similar stratum within the sampling region, or from sample units representing the same or similar strata from a different region, to produce per hectare statistics. Although per hectare statistics may have estimates of precision, the application of the statistics to the unsampled stratified area cannot be reported with an accompanying standard error of prediction.

For example, if the stratum of interest is a certain ownership (i.e. private) and there are no sample units located on private land, the appropriate units from crown land may be substituted, compiled, and applied to the area. Such estimates have unknown precision.

Indirect Method

The indirect method employs an intermediate model (e.g. stock table, yield table) to calculate the inventory estimate. The model is compiled directly from sample units, and can be accompanied by a sampling error. Models are typically created for certain combinations of classification criteria that influence the standing volume and its distribution (e.g. species composition, stand height, density). Sample units within the desired combinations are grouped, and unit estimates are averaged to compute per hectare statistics. These are representative statistics that are applied on a stand by stand basis to the area of the forest condition (ie. the area within the desired combination of classification criteria) whenever it occurs to derive the inventory estimate. An estimate of error cannot be calculated when the model is applied outside the stratum or when applied as a representative statistic on a stand by stand basis.

The representative statistics of the model may be applied to local conditions that are not yet sampled or that contain no sample units. Representative statistics may be taken from a similar type within a sampling region, or from the same or similar type from a different sampling region. Representative statistics are applied to the area on

a stand by stand basis, so no sampling error can be calculated.

Inventory statistics may be expressed as tables or formulated as equations. Tables are generally in the form of stand and stock tables, showing various size classes, combinations of species, and levels of utilization. One example is the static stand and stock table illustrated in Table 2. The stand and stock table format can be used in both direct and indirect methods of estimation. When the dimension of time is added it becomes a yield table (Table 3). The dynamic yield table can provide essentially the same statistics as the static tables but, because yield tables model stand development over time, they can be used to predict estimates.

Report Compilation

A report estimate (*16*) is generated by simply multiplying area by its per unit area parameter (e.g. in the case of volume: ha x m^3 /ha = m^3). The per unit area statistic is created following the direct (*11*) or indirect (*12*) methods of estimation. The direct report is compiled by applying the estimate for a stratum to the aggregated area of the stratum. Subsequent reports, for different groupings, are created by post-stratifying classification criteria and regrouping sample units to create the stratum estimate. Multiplying the stratum estimate by the aggregated area for the stratum generates the subsequent report. Reports created following the direct method of volume estimation cannot be used to make projections, nor are they suitable for management modelling at the stand level. Reports are generated for different subgroupings by accumulating area stand by stand (i.e. selecting stands from the stand attribute list (*14*)). The area is then multiplied by the appropriate statistic, derived from the indirect method, to estimate the parameter of interest. This parameter can be used for projections as well as for management models.

Inventories have been slowly changing to accommodate the shift to more intensive forest management. More dynamic data, which include major changes to the forest resulting from fire, insects, disease, harvesting, and silviculture, as well as subtle changes resulting from growth and mortality, have been added to the inventory to feed forest management models (e.g,. wood supply analysis). The inventory update options are illustrated in Figure 1 as calculated update (*13*) and observed update (*17*).

Calculated update is an ongoing process at the forest stand level and is based upon growth and yield tables. The appropriate table is applied to the latest stand description to project the stand to the present or into the future.

Major cover type changes, resulting from harvesting, reforestation, or catastrophe are added to the forest map base (*17*). The attribute list is brought up to date to reflect changes in the area and description of forest stands, and to compile and report new inventory estimates. Major cover type changes make the initial estimates obsolete. Subsequent volume estimation and report compilation uses the best information available; the procedures use indirect methods and so cannot be accompanied by an estimate of statistical accuracy.

The addition of an update allows the inventory to be maintained or projected into the future, completing the forest management information cycle.

Discussion

The model illustrated in Figure 1 can be used as a framework to describe provincial forest management inventories. The figure may not mirror each situation; however, most efforts are aimed towards a more complete match, or to strengthening individual components of the model. Characteristics of provincial inventory procedures related to Figure 1 are listed in Appendix 1.

Weaknesses associated with the inventory process relate more to the understanding and application of the model than to the individual components. The main problems are associated with the sequencing of components, photo interpretation, the establishment of sample units, and the application of single tree equations.

The sequence of events illustrated in Figure 1 is not always followed. Timing, cost, and historical or administrative factors may influence how the inventory is conducted. Volume sampling may precede the creation of the final forest type map. Preliminary map information would form the basis of the sampling plan and be used for stratification and sample plot location. The use of preliminary map information allows volume sampling to begin in the time period between photo interpretation and final map creation. Problems

Table 2. Average Stand and Stock Table
Softwood - Pine
Density Class 0-50%
Height Class 0-15 m
Petawawa Research Forest

	DIAMETER (cm)*						TOTAL	
	0-9.9		10-24.9		25+			
	Volume** (m^3/ha)	Trees/ha	Volume (m^3/ha)	Trees/ha	Volume (m^3/ha)	Trees/ha	Volume (m^3/ha)	Trees/ha
Species								
wP	0	0	4.40	30	13.36	22	17.76	52
bS	7.34	718	23.42	316	3.21	7	33.96	1041
wS	0	0	1.01	10	0	0	1.01	10
bF	0.49	40	0	0	0	0	0.49	40
L	0	0	1.49	5	0	0	1.49	5
rM	0	0	0.81	6	0	0	0.81	6

*Diameter at breast height
**Gross merchantable
Source: 1985 PNFI Forest Inventory

Table 3. Coniferous Yield Table for mixed types of Alberta*

Total age (yr)	Top height (m)	Gross volume (m^3/ha)	Gross MAI (m^3/ha/yr)	Net pulp volume (m^3/ha)	Net MAI (m^3/ha/yr)	Basal area (m^3/ha)	Number of trees (per ha)
10	0.0	0.0	0.0	0.0	0.0	0.0	0
20	3.24	0.0	0.0	0.0	0.0	0.0	0
30	7.52	0.0	0.0	0.0	0.0	0.0	0
40	11.78	0.0	0.0	0.0	0.0	0.0	0
50	15.65	48.18	0.96350	47.88	0.95753	7.02	314
60	19.01	103.50	1.72501	102.71	1.71189	13.17	399
70	21.89	152.72	2.18168	150.78	2.15397	17.96	421
80	24.34	195.65	2.44562	193.16	2.41456	21.83	428
90	26.42	232.72	2.58579	229.37	2.54856	25.01	430
100	28.20	264.61	2.64608	260.64	2.60639**	27.65	431
110	29.72	292.03	2.65482**	286.66	2.60597	29.86	432
120	31.03	315.66	2.63053	209.86	2.58213	31.72	433
130	32.16	336.11	2.58543	329.92	2.53785	33.30	435
140	33.15	353.86	2.52761	347.35	2.48110	34.66	436
150	34.02	369.37	2.46244	362.57	2.41713	35.83	437
160	34.78	382.96	2.39351	375.91	2.34946	36.84	438
170	35.45	394.94	2.32320	387.68	2.28046	37.73	439
180	36.05	405.56	2.25309	396.76	2.20420	38.51	441

*Good sites, minimum DOB measured at stump height = 13 cm (stump height = 0.30 m), minimum top DIB = 7.00 cm
**culmination of MAI
Source: Alberta Energy and Natural Resources. 1984. Alberta Phase 3 inventory, yield tables for unmanaged stands, ENR Dept. Report 60a.

arise when changes are made to type lines or stand descriptions in the production of the final map. Sample units must be post-stratified according to the final map, resulting in some strata being oversampled, some being undersampled, and some being not sampled at all.

Under some circumstances volume sampling is not done. In these circumstances old sample units may be substituted, or the entire emphasis may be placed on the interpreted forest stand description. When old sample units are used volume can be determined by either direct or indirect methods. When the emphasis is placed entirely on photo interpretation, volume can only be determined by indirect methods, that is, relating the area of the forest stand to an appropriate, established, representative stand "look up" table. In the latter case, an accurate area estimation and forest stand description are the primary objectives of the inventory.

Administrative factors also influence how the inventory is conducted. For example, complex tree volume equations may be developed by one group and applied by another group. As a result, equations may not be fully understood nor properly applied. Individual tree equations are often developed once and applied on subsequent inventory equations. This factor may reduce the number of components followed in the inventory process on any one occasion.

Subjective photo interpretation may result in a wide range of forest compositions and structures being ascribed to the wrong type. This would affect the relationship between photo interpretation and ground plot location and, therefore, subsequent determination of volume. There are potentially four different situations as outlined in Table 4. An error in ground plot location may result in the wrong population being sampled, leading to a biased sample. An error in interpretation, followed by correct ground plot location, maintains the objectivity of the sample design but increases the variance of the sample, resulting in a wider confidence limit attached to the final estimate. An error in both interpretation and ground plot location would seriously affect the objectivity of the sample, compromising the accuracy of inventory results.

Documentation of the sampling design employed in management inventories is generally inadequate. Statements of statistical accuracy are often only available for a few broad statistics at the management unit level. It may not be possible to compute an estimate with precision for all possible strata available from a large and complex forest inventory. The situation becomes more complex as the inventory becomes more dynamic, with updates through observation and calculation. There appears to be considerable room for better application of statistical science to provide the forest manager with statements of confidence for the more important estimates.

Instructions for establishing sample units are generally sound and well documented. However, if the quality of the field work is not up to standard, follow-up check cruising, or quality control, may not always identify poor quality work. As a result, some questionable data may be accepted, contributing unknown bias to the final estimate.

Good regional single tree volume equations are generally available. Problems arise with the understanding and application of these equations. In theory, tree volume equations constructed from regression analysis should only be applied to that portion of the forest from which they were derived. In practice, however, equations are applied regionally with the assumption that the local fit is acceptable. This is done despite the well known fact that tree shape is variable within a region. Given equations may be of questionable value in some situations. Substitute equations may be applied to fill voids but these are not always verified. As well, equations may not be designed to handle changes in utilization, and may not have estimators for cull. Volume equations are assumed to contribute no bias or error to the final volume estimate. Improper application of tree equations (e.g., derived from another population), badly fitted equations, and the use of wrong utilization factors can cause significant biases.

Evolution of the Inventory Process

Forest management inventory was first developed in Canada to identify the volume and location of the forest resource at a particular point in time. The usual purpose for the inventory was to provide data for long term timber management planning, allowable cut calculations, and to establish harvest areas.

Table 4. The relationship between photo interpretation and ground plot location

Interpretation	Ground plot location	Implication
Correct	Correct	According to design
Correct	Incorrect	Biased sample
Incorrect	Correct	Unbiased sample, increased variance, less precise estimate, wrong label
Incorrect	Incorrect	Biased sample, no known precision

Forest management has been changing in Canada, from exploitation of an abundant resource towards more intensive management of a scarce resource. Old, rigid inventories cannot satisfy the changing needs of management. Today managers require accurate and timely data in a format which permits an effective evaluation of alternative courses of action. As the emphasis shifts from timber to the forest as a whole, more and more non-timber related data are necessary for decision-making. To help handle the wide variety of forest management data, prediction models have been developed which allow the manager to analyze the likely effects of various activities on forest development.

The static timber inventory is evolving into a dynamic forest resource information system. The new system is more accurate and timely for several reasons. For example,

- growth and yield functions allow the inventory to be updated to the present or projected into the future; the effects of various management options can be simulated by "growing" the inventory into the future; predicted results can be confirmed with the next inventory or updated inventory, and

- we can update an inventory by incorporating changes such as reforestation, harvest, fire, insects and disease, and land use changes.

Computer technology has had a major impact on inventory compilation, making it possible for more rapid and complex mathematical calculations to be carried out and for inventories to be updated, projected, and predicted.

Individual components in Figure 1 may change in the future. For example, new technological developments in remote sensing may change the way a map is prepared or the technique by which volume sampling is carried out, i.e. sampling versus measuring the entire population. However, the basic compilation process, as described in Figure 1, is expected to remain valid.

Acknowledgments

The authors wish to thank J.J. Lowe for his patience and direction in discussions of the topic and during preparation of the manuscript, Canadian Forest Inventory Committee members (Appendix 3) for their cooperation in discussion of provincial procedures and for their review of this report, and to the editorial review board members J. Osborn, D. Demers, B. Haddon, and R. Hirvonen for their constructive criticism.

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APPENDIX 1

Characteristics of Provincial Forest Inventory Procedures

	British Columbia	Alberta	Saskatchewan
METHODOLOGY			
a) inventory cycle	a) 10-year-cycle with annual updates for changes in history	a) no fixed period	a) 15-year-cycle, (based on economic conditions and forest industry activity)
b) sampling design	b) modified, stratified random sampling		b) sampling with partial replacement and stratified random sampling
c) intensity & accuracy	c) timber volumes by aggregate types by Timber Supply Area (TSA) at a ±10% accuracy at the 95% confidence level	c) depends on cover group and volume (gross or net), ranges from ±10% at the 75% confidence level to ±30% at the 67% confidence level	
STRATIFICATION			
a) - stratification criteria	a) species composition, 9 age classes, 8 height classes, crown closure, stocking class, stand history, stand structure, environmentally sensitive area	a) volume sampling region (VSR), density (crown closure), height, primary and secondary species, cover group	a) survey area, species association, height, density, drainage, texture, year of origin
TEMPORARY SAMPLE PLOTS			
a) - attributes measured	a) all trees ›7.5 cm - species, dbh, total height, crown class, layer, tree class, pathological remarks, tree quality; small trees ‹7.5 cm dbh and 7.3 m in height - species, tree count; sample trees - species, dbh, total height, total age, crown class, layer radial increment	a) species, dbh, total height, crown class, visible saw defect, cull suspect class, stump diameter, 10 and 20 year increment width, total age	a) all trees - species, topography, density, slope, aspect, soil texture and drainage, year of origin, dbh; sample trees - species, height, crown position, sound wood, age, quality class, tree class, pathological remarks
b) - type of plot	b) fixed area and variable radius (prism)	b) variable radius (prism), some fixed area, large scale photo (LSP)	b) fixed area, modified 3P
STEM ANALYSIS			
a) - purpose	a) 1. whole stem cubic metre volume 2. decay, reduction factors for calculation of net tree volumes 3. site curves for: coastal species - Douglas-fir, western hemlock, western red cedar, balsam fir interior species - lodgepole pine, spruce	a) gross single tree volume equation merchantable ratio factors height/diameter relationships taper equations site index equations	a) volume and taper equations
b) sampling design	b) for volume and decay - fixed area and variable radius (prism) plots	b) fixed area or variable radius (prism)	b) random; subsample of inventory plots based on 3P sampling techniques
c) by species or strata	c) species, risk group, maturity class	c) VSR, species, and cull suspect class	
TREE FUNCTIONS			
a) - model used	a) log volume = $b_1 + b_2 \log dbh + b_3 \log ht$ individual tree volumes, base 10 logarithmic	a) Schumacher's function $V = a(DBH^b)H^c$ merch. vol. = $a^a (DBH^b)H^c \times MR$ $MR = a + bg + cg^2$ $g = \left(\frac{H-h}{H}\right)^2 \cdot \left(\frac{d}{D}\right)^4$ h = stump height H = total height d = top diameter MR = merchantable ratio	a) segmented taper model - total and merchantable tree volumes; log volumes

	British Columbia	Alberta	Saskatchewan
PERMANENT SAMPLE PLOTS			
a) type of plot	a) fixed area, usually 0.025 ha but can be 0.035 ha or 0.015 ha	a) fixed area, 0.02 ha to 0.20 ha = 100 trees per plot on newly established plots	a) fixed area, size varies
b) measurements taken	b) mean age, mean height stems ≥7.5 cm dbh - species, dbh, height, tree class, pathological remarks, layer, total age, radial increment	b) trees ≥9.1 cm dbh - species, dbh, height on 30% of trees, tree condition, crown class; ingrowth by species and dbh; regeneration by species and height class; age collected on selected stem analysis tree well outside plot	b) species, dbhob, crown class, ingrowth, some heights, regeneration by species and height class
c) duration	c) periodic - 1920s, early 1960s	c) program began in 1960	c) established late 1940s, early 1950s, mid 1970s
COVER TYPE TABLES			
a) variables		a) for each cover type, cover group (species, height, density) in a VSR wood volumes and stems per ha by species and utilization standard	a) major species combinations, dbh class, merchantable and whole tree volume (pulp and saw), stems per ha by utilization standard
GROWTH AND YIELD FUNCTIONS			
	Volume Calculation Equations: (1) Ek-Payandeh whole stem yield function (7.5 cm+) VOL75 = B1*SI**B2*(1-EXP(B3*AGE))** (B4*SI**B5) (2) Volume ratios calculated for all other levels of utilization (12.5/17.5/22.5 cm+) VOLRAT = 1.0 + (B1+(B2*SI)) / (AGE-(B3+B4/(SI-B5))) (3) Volume at higher level of utilization VOLUME AT 12.5 CM+=VOL75*VOLRAT125 VOLUME AT 17.5 CM+=VOL75*VOLRAT175 VOLUME AT 22.5 CM+=VOL75*VOLRAT225 Diameter Calculation Equation: Modified Chapman-Richards DQ=B1*SI*(1-EXP(B2*AGE))**B3*EXP(B4*SI) Growth and yield estimates for species groups within a Forest Inventory Zone	logistic function V=f(age, site index) Yield tables for pine, white spruce, mixedwood, and deciduous by site index and merchantability class	a) $V = bD^2H$ b depends on dbh class and species; calculated by survey area and growth type
MANAGEMENT PLANNING MODELS	MUSYC (multiple use sustained yield calculation) TIMBER RAM (area/volume check) IFS YIELD (simulation model) TRIM (Timber resource inventory model)	TIMBER RAM (area/volume check)	

	Manitoba	Ontario	Québec
METHODOLOGY			
a) inventory cycle b) sampling design c) intensity and accuracy	a) -0 year active areas, 20 year non active areas c) ±20%	a) 20 year b) subjective c) approx. 1 plot/2 sq. km.	a) 10 year b) stratified c) ±5% error at the 95% confidence level, varies by stratum
STRATIFICATION			
a) stratification criteria	a) 67 subtypes, 3 site classes, 6 maturity classes, 4 crown closure classes	a) not applicable	a) species group, height, density, age class
TEMPORARY SAMPLE PLOTS			
a) attributes measured	a) all trees - species, dbh, height, age, crown class, site	a) species composition, basal area, age, height, stocking, site class (derived) ownership	a) height class, age class, crown closure, forest type, cover type (species) cause of disturbance, defoliation, origin, slope class, second story silvicultural treatment, regeneration (stems <1.5 m height)
b) type of plot	b) variable radius (prism) - BAF 2M	b) variable radius (prism BAF 2M) - established for ground truth, not for volume estimation	b) 0.04 ha circular plots 0.0004 ha circular plots - regeneration
STEM ANALYSIS			
a) purpose b) sampling design c) by species or strata	a) no stem analysis estimate cull from mill return data	a) cull equations c) by species and eco-region	a) to produce general volume equations
TREE FUNCTIONS			
a) model used	a) $V = a + \frac{b\,DBH^2 \times H}{100}$ a - regression constant b - regression coefficient	a) use stand volume tables (not tree equations)	a) general volume equation by species for province

	Manitoba	Ontario	Québec
PERMANENT SAMPLE PLOTS			
a) type of plot b) measurements taken	a) fixed area, 0.05 ha b) species, dbh, height, crown class, age, structure, soil texture and moisture, status, distance		a) fixed area 0.04 ha; rectangular and circular b) general characteristics, age class, number merchantable stems, species and numbers of regeneration, number seedlings, drainage, topography, aspect, slope, soil type, vegetation, stems; status, species, dbh, crown class, branching, defoliation, vigour, pathology defects, utilization, quality, sample trees; total height, merchantable height, age, rot, 5 and 10 year growth, stump diameter
c) duration	c) remeasure every 5 years		c) since 1970 - remeasure every 8-10 years
COVER TYPE TABLES			
a) variables	a) for intermediate age and up - species, site and density combinations by groups of Forest Management Units	a) Plonski's normal yield tables by working group (major species) and site class Used as stand volume tables with stand volume estimates adjusted from normal to actual by stand stocking	a) by stratum; species group, height, dbh, age, by sampling unit; stand and stock, basal area
GROWTH AND YIELD FUNCTIONS			
	natural and plantation yield tables	Plonski's normal yield tables	Boudoux Yield Table for softwoods Carpentier Yield Table for hardwoods Plonski Yield Table for cedar
MANAGEMENT PLANNING MODELS			
		OWOSFOP (Ontario Wood Supply and Forest Production Model)	Silva model is used to determine allowable cut, separate components are used for hardwoods and for softwoods

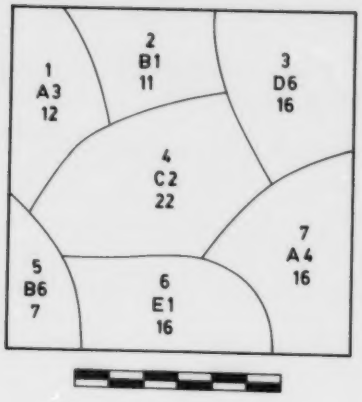
	New Brunswick	Nova Scotia	Prince Edward Island
METHODOLOGY			
a) inventory cycle b) sampling design c) intensity and accuracy	a) no fixed period b) stratified random sampling c) standard error for total volume for a stratum to be within 10% at the 95% confidence level	a) 11-12 year b) 3 stage 3P - dendrometry c) ±15% standard error by ownership and by county at the 90% confidence level for all species (0.021 plots/ha)	a) 10 year b) simple random sampling c) ±10% for all species in a forest management unit at the 90% confidence level, standard error 2.8-39.3% for strata on a provincial basis, 2.0% for all strata together for province
STRATIFICATION			
a) stratification criteria	a) species mix, development stage, crown closure	a) ownership, cover type, maturity class, county	a) cover type (S, SH, HS, H, Alder), stand height, stand density (low, medium, and high)
TEMPORARY SAMPLE PLOTS			
a) attributes measured	a) merchantable trees ›9 cm dbh - species and diameter class, (all ownerships)	a) volume, forest code (maturity and silvicultural treatments), cover type, average total height, species, second storey, basal area, capability, crown closure, slope, operability, stand improvement, aspect, diameters, ring measurement, product	a) species, dbh, height, product class, defect, age
b) type of plot	b) variable radius (prism)	b) variable radius (prism)	b) variable radius (prism) for volume (all trees ›9 cm dbh) fixed radius for biomass (all trees ›1.3 metres in height)
STEM ANALYSIS			
a) purpose	a) volume table construction construct height/age relationships cull determination	a) no stem analysis, however, individual trees are selected (using 3P) to be measured with a dendrometer to determine volume by species, product, and grade	a) volume and growth
b) sampling design c) by species or strata			c) species
TREE FUNCTIONS			
a) model used			a) Total volume (TV) = $A*DBH^{b*}H^{c}$ Merchantable volume = $TV/A+BX+CX^2$ $x = ((1+hs/ht)(DTop^2/DBH^2))$ hs = stump height ht = tree height

	New Brunswick	Nova Scotia	Prince Edward Island
PERMANENT SAMPLE PLOTS			
a) type of plot	a) fixed radius	a) 0.0404 ha fixed area circular plots	a) fixed radius, 0.04 ha and 0.02 ha circular plots
b) measurements taken	b) inside plot (all stems ›1.0 cm dbh) species, age class, age and cause of death SPF stems ›9.0 cm, dbh, crown ratio, leader damage, current defoliation % class, cumulative defoliation % class, proportion top broken, wound type, wound depth, wound diameter, wound location, bird damage, lean; selected stems (outside plot) species, dbh, age, core, age class, 5 and 10 year radial increment, height; selected stems (mainly inside plot) species, diameter, height; subplots, number coniferous and deciduous tree/ shrub stems ‹2 m but ›30 cm, mean height of the tree/shrub layer, most abundant species, % cover of non-woody vegetation, % crown closure, number dead trees ≥2 m tall and ›9 cm dbh by dbh, height and condition class, number dead trees ‹2 m tall and ›9 cm dbh	b) dbh, merchantable height, total height, stump height, top diameter if defect warrants it, crown class, tree condition class (regeneration - dominant species, degree of stocking) age of plot, basal area, tree class	b) dbh, total height, age, live crown ratio, site information, soil samples
c) duration		c) since 1965	c) less than 10 years
COVER TYPE TABLES			
a) variables		a) county, ownership, maturity class, stand type, cover, species, product, dbh	a) stand and stock tables for district and stratum, species, dbh and product classes; stems per hectare, basal area and volume expressions compiled for each class; gross total volume for each district, stratum and combination thereof
GROWTH AND YIELD FUNCTIONS			
	1. Empirical yield tables for natural stands Vol = f(age, species, crown closure) 2. Simulation model for managed stands Driving variables = species, soil group, initial density	Regressions based on site, stocking, average diameter and height	Site index
MANAGEMENT PLANNING MODELS			
	FORMAN - simulation model	SAWS (Strategic Analysis Wood Supply) model	FORMAN Wood Supply Model

	Newfoundland		
METHODOLOGY			
a) inventory cycle b) sampling design c) intensity and accuracy	a) 10 year b) stratified random sampling c) standard error ±5% for gross merchantable volume at the management unit level, at the 95% confidence level		
STRATIFICATION			
a) stratification criteria	a) management unit, height, density, working group (BF, BS, SH, HS, WB, TA)		
TEMPORARY SAMPLE PLOTS			
a) attributes measured b) type of plot	a) trees ≥9 cm dbh, species, dbh, height, age; cull and form plots are established separately b) 0.02 ha fixed area square plots		
STEM ANALYSIS			
a) purpose c) by species or strata b) sampling design	a) volume and cull tree density models; decay and cull assessment; sawlog tree volume models		
TREE FUNCTIONS			
a) model used	a) Honer's equations with separate coefficients by Management Unit		

APPENDIX 2
The volume estimation procedure

Mapping Phase



Map Symbol
3 - stand number
D - forest type
16 - area (ha)

Stand Attribute List

Stand	Description	Stratum	Area (ha)
1	3	A	12
2	1	B	11
3	6	D	16
4	2	C	22
5	6	B	7
6	1	E	16
7	4	A	16

Stratification
(Aggregate stands)

Stratum A - Aggregate stands 1 and 7 → area = 28 ha

Sampling Phase

1. Allocate sample units to strata.
(assume Stratum A has three plots)

2. Establish sample unit.
(sample plot measurement for an individual tree from one plot)

Plot	Species	dbh	Height	other
1	Spruce	20 cm	20 m	

*Could be other data such as species quality, form, age

3. Determine individual tree volume

$V = f(h, d, f)$

V - volume
h - height
d - dbh
f - form

$V = .25\ m^3$ for the spruce tree measured in plot 1.

4. Determine the amount that the individual tree represents on an per unit area basis.

The 20 cm, 20 m spruce represents - 64 trees/ha
- 16 m^3/ha

The individual tree volumes are added to determine the plot estimates. The plots are averaged to compute the inventory estimates.

If there were two spruces of the same dimensions in every plot in Stratum A, the final inventory estimate would be

$\frac{(16+16)+(16+16)+(16+16)}{3} = 32\ m^3/ha \pm x$ of spruce

Compilation Phase

Direct — Stratum A, 28 ha x 32 m^3/ha (spruce) = 896 m^3 spruce ±x

Indirect — Stand 1 (A portion of stratum A), 12 ha x 32 m^3/ha (spruce) = 384 m^3 spruce ±?

APPENDIX 3

Canadian Forest Inventory Committee
Provincial and Territorial Members

Province	Member	Title
Newfoundland	R. Mercer	Director, Forest Management Division
Nova Scotia	F.R. Wellings	Director, Resource Management, Planning and Mensuration
New Brunswick	T. Erdle	Specialist, GIS and Wood Supply Modelling
Prince Edward Island	W.M. Glen	Manager, Silviculture Development
Québec	D. Demers	Chef de la compilation et publications
Ontario	J.E. Osborn	Manager, Forest Management Information
Manitoba	R.H. Lamont	Chief, Forest Management
Saskatchewan	L.W. Stanley	Manager, Forest Inventory
Alberta	D.J. Morgan	Forester I/C, Forest Measurement Section
British Columbia	F. Hegyi	Director, Planning and Inventory Branch
Yukon	K. Rymer	Project Forester
Northwest Territories	C.R. Carlisle	Forest Management Technician